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Influence of oceanographic conditions on the spatial and temporal distribution of chlorophyll-a in the coastal waters of the Brazilian Amazon region (São Luís-MA)

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ABSTRACT

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The present study focused on São Luís Island located between São José and São Marcos bays. It is part of the Brazilian Amazon coastal zone, which is dominated by a macrotidal regime, tidal currents, northeast winds, high rainfall rates and elevated river discharge. The present study aimed to evaluate the influence of climatic, hydrodynamic and hydrological variables on the concentration of chlorophyll-a in coastal waters of three beaches located in São Marcos Bay. Data were collected at three stations over a 12-hour period in December, 2008 (dry season, low river discharge), March, 2009 (rainy season, rising river discharge), June, 2009 (rainy season, high river discharge), and Sep-Oct, 2009 (dry season, falling river discharges). The highest chlorophyll-a concentrations were recorded at São Marcos beach and Calhau, and with the highest values being recorded in March and June, 2009 (high fluvial discharge). At São Marcos the average values ranged from 5.18 mg/m³ in December to 15.99 mg/m³ in March. At Calhau, concentrations varied from 2.86 mg/m³ (December) to 16.83 mg/m³ (June), and between 4.42 mg/m³ (December) and 12.38 mg/m³ (June) at Olho d'água. The turbidity does not appear to be a factor limiting chlorophyll-a concentrations, given that the highest values were recorded in the rainy season, and phytoplankton blooms were observed during this period at São Marcos and Calhau. The probable increase in the concentration of dissolved nutrients may have affected the local phytoplankton biomass, which had a much greater concentration in March and June.

ADDITIONAL INDEX WORDS: *Amazon coast, salinity, turbidity, phytoplankton biomass.*

INTRODUCTION

The high chlorophyll-a concentrations in coastal areas is related mainly to the amount of nutrients that reaches those waters and to the high sunlight penetration. On the Amazon shelf, chlorophyll-a concentrations are generally considered to be an index of phytoplankton biomass and considerable algal blooms occur on these waters, and the source of the nutrients that sustain the algal blooms and the high turbidity have been widely discussed by Edmond *et al*. (1981); DeMaster *et al*. (1986); Geyer *et al*. (1996); Santos *et al*. (2008); amongst others. These authors studied the influence of the Amazon and Pará Rivers on the distribution of physical and chemical parameters, as well as on the phytoplankton biomass at the Amazon shelf and adjacent oceanic areas. However, little is known on these variables in the Amazon coast, principally far from Amazon plume influence.

The Amazon coast extend by more than 2,500 km and it is traversed by dozen estuaries, which provide a plentiful supply of fluvial sediments, dissolved nutrients and organic material for the local coastal aquatic ecosystems.

The present study focused on São Luís Island in the Gulf of Maranhão. It is part of the Brazilian Amazon coastal zone, which is dominated by a macrotidal regime, strong tidal currents, northeast winds, high rainfall rates and elevated river discharge (Silva *et al*., 2009). Studies on spatial and temporal variations of chlorophyll-a concentrations are scarce in that coastal zone. Given this, the present study aimed to evaluate the influence of climatic (wind and rainfall), hydrological (salinity and turbidity) and hydrodynamic (tides and waves) variables on the concentration of chlorophyll-a in coastal waters of three beaches (São Marcos, Calhau and Olho d'água) located in São Marcos Bay.

STUDY AREA

The 640 km of coastline of Maranhão is the second largest of any Brazilian state. This littoral is characterized by an irregular outline with many islands, inlets, estuaries and mangrove forest, in addition to extensive dune fields with lagoons and salt and freshwater swamps. Maranhão's coastal zone is divided into five sectors: (i) Gulf of Maranhão; (ii) Eastern coast; (iii) Western coast; (iv) Maranhão Basin; and (v) Parcel de Manuel Luís State Marine Park. The present study focused on São Luís Island in the Gulf of Maranhão. The littoral of São Luís is 35 km long, and is located between São José and São Marcos bays (Figure 1).

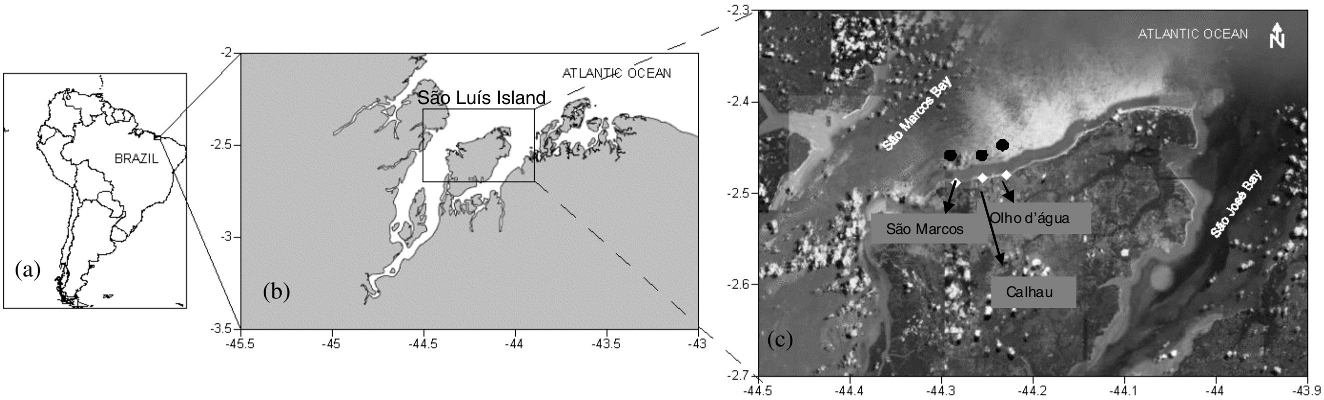


Figure 1. (a) Location of São Luís within Brazil; (b) São Luís Island; and (c) Studied beaches of São Luís (Image from Google Map).

It is part of the Brazilian Amazon coastal zone, which is dominated by a macrotidal regime (up to 7 m), strong tidal currents (up to 1.2 m), wave periods lower than 8 s and maximum wave heights, Hb (up to 1.1m) (DHN, 2009; Silva *et al.*, 2009).

The climate is rainy tropical (AW', according to Köppen System) with two main seasons, the wet and dry. The wet season occurs normally from December to May, and is characterized by a mean rainfall that exceeds 1,500 mm and temperatures falling to a minimum of 20ºC. In contrast, the dry season occurs during the other months of the year and it is characterized by a mean rainfall up to 200 mm and temperatures up to 33ºC. The wind climate shows also a seasonal pattern, with the strongest winds blowing during the dry season, mainly from August to January, and moderate winds blowing during the wet season (Porto de Itaqui, 2008).

METHODS

Data were collected at three stations over a 12-hour period in December, 2008 (dry season, low river discharge), March, 2009 (rainy season, rising river discharge), June, 2009 (rainy season, high river discharge), and Sep-Oct, 2009 (dry season, falling river discharges). Climate data (wind and rainfall) were obtained for each of the studied month from the Brazilian National Institute of Meteorology (São Luís A203 station). Tidal range and offshore wave data were provided by the Brazilian Navy's Hydrographic and Navigation Department and Weather Forecasting and Climatic Studies Center, respectively. A CTD data logger was fixed to the sea floor at a depth of 1.8 meters and programmed to record average salinity every 10 minutes. Turbidity, dissolved nutrients and chlorophyll-a concentrations were obtained through the analysis of sub-surface water collected in a Niskin oceanography bottle every 6 hours. In the laboratory, turbidity was assessed using a turbidity meter. Dissolved nutrients were analyzed following Strickland and Parsons (1972) and Grasshoff *et al.* (1983), while the concentration of dissolved nutrients and chlorophyll-a were measured using Strickland and Parsons (1972) methods.

RESULTS AND DISCUSSION

The Amazon littoral presents two distinct seasons, with high precipitation rates in the first half of the year (over 2,000 mm), and a dry period in the second half (Figueroa and Nobre, 1990; Marengo, 1995). During the studied months, rainfall was greatest in March (471.6 mm) and June (193.20 mm), and lowest in December (16.8 mm) and September, (0.0 mm). By contrast, stronger maximum monthly winds and offshore wave heights (*Ho*s) were recorded in the dry season (average of 7.91 m/s and 0.84 m in December, and 7.45 m/s and 0.94 m in September, for winds and *Ho*s, respectively) in comparison with the rainy season (average of 4.29 m/s and 0.68 m in March and 3.48 m/s and 0.47 m in June). The study area is dominated by macrotidal conditions with predominant tidal currents (Silva *et al.*, 2009). Local tides are semidiurnal and the highest ranges during the study period were recorded on December 8-9th, 2008, with ranges of 5.9-6.1 m. On March 24-25th, 2009, values of 5.5-5.6 m were recorded, while tidal range was 5.1-5.3 m on September 30th/October 1st, and 5.0-5.2 m on June 11-12th.

The highly seasonal climate associated to the variation in hydrodynamic conditions determined the observed seasonal fluctuations on the studied hydrological variables. Salinity (Figure 2) was lower in June (rainy season), when the fluvial discharge in São Marcos was at its highest, and higher in December (dry season), when the discharge was at its lowest. Recorded salinity levels were similar on all three beaches: 17.15 psu in June and 35.84 psu in December at São Marcos, 16.64 psu and 36.00 psu, respectively at Calhau, and 17.47 psu and 36.15 psu at Olho d'água. Salinity values were significantly lower in the rainy season, as a result of the high precipitation rates – especially in March – and increased fluvial discharge, culminating in June. This seasonal pattern has been recorded at other sites along the Amazon coast, with salinity varying from < 10 psu in the rainy season to > 35 psu in the dry (Sousa *et al.*, 2009; Monteiro *et al.*, 2009; Pereira *et al.*, 2009; Silva *et al.* 2009).

By contrast, turbidity (Figure 3A) was highest in the rainy season (the highest fluvial discharge), and lowest in the dry season. Turbidity ranged from 13.35 NTU (September) to 127.00 NTU (March) at São Marcos, 18.18 NTU (September) to 44.37 NTU (March) at Calhau, and 20.68 NTU (December) to 61.50 NTU (March) at Olho d'água. In Amazon shelf, the water is turbid throughout the year due to great fluvial discharge, mainly during the rainy season (DeMaster and Pope, 1996; Nittrouer and DeMaster, 1996). The highest turbidity data was found in the rainy season, mainly in March, when fluvial discharge was great.

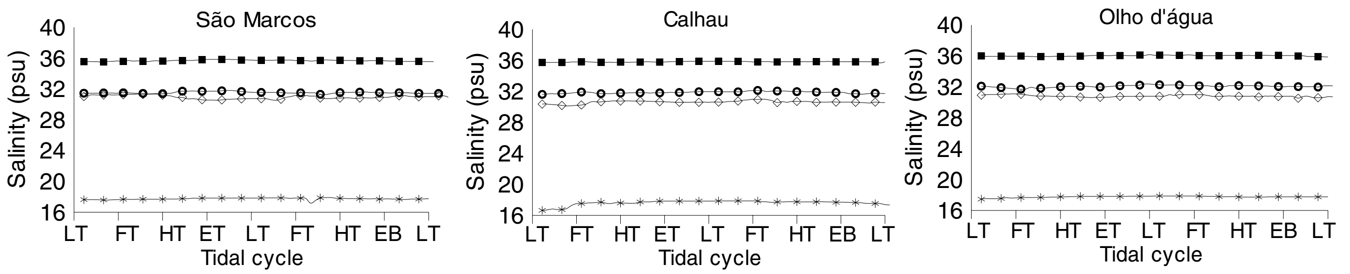


Figure 2. Salinity values in coastal waters of São Luís. LT Low Tide, FT Flood Tide, HT High Tide and EB Ebb Tide.

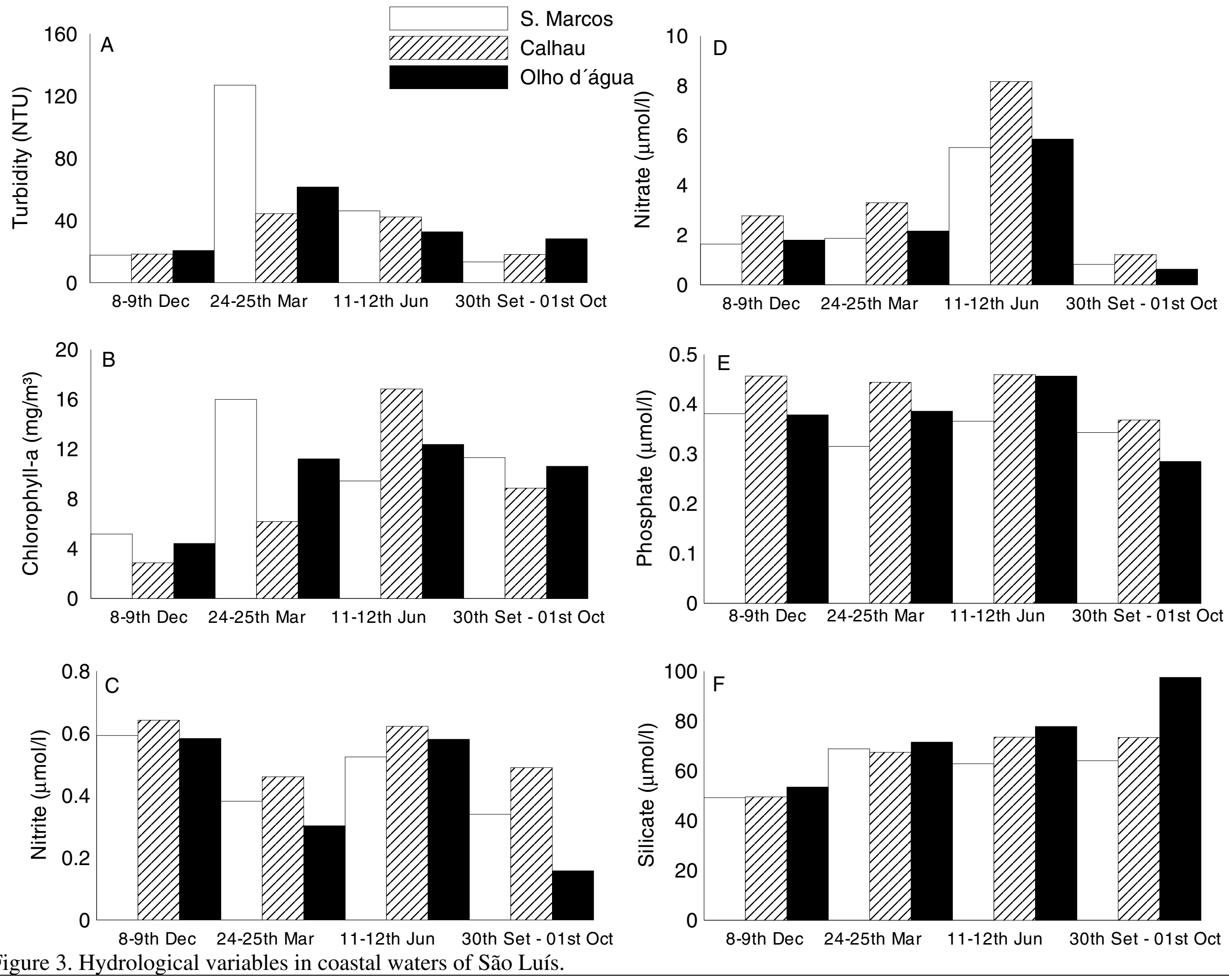


Figure 3. Hydrological variables in coastal waters of São Luís.

Overall, the highest chlorophyll-a concentrations (Figure 3B) were recorded at São Marcos beach and Calhau. However, turbidity does not appear to be a factor limiting chlorophyll-a concentrations, given that the highest values were recorded in the rainy season, and phytoplankton blooms were observed during this period at São Marcos (March) and Calhau (June). At São Marcos the average values ranged from 5.18 mg/m³ in December to 15.99 mg/m³ in March. At Calhau, concentrations varied from 2.86 mg/m³ (December) to 16.83 mg/m³ (June), and between 4.42 mg/m³ (December) and 12.38 mg/m³ (June) at Olho d'água. High concentrations were also recorded in September, when the water was less turbid, and sunlight penetration was at its maximum. An additional factor may have been the strong wind speed and greater wave heights recorded during this month, which possible contributed to the re-suspension of phytobenthic species into the pelagic environment.

The highest nitrite concentrations were recorded in December (0.642 µmol/l at São Marcos, 0.593 µmol/l at Calhau and 0.583 µmol/l at Olho d'água), whereas the lowest values were obtained in September (0.340 µmol/l at Calhau and 0.158 µmol/l at Olho d'água (Figure 3C). The highest concentrations of nitrate (8.164 µmol/l at São Marcos, 5.515 µmol/l at Calhau and 5.851 µmol/l at Olho d'água) and phosphate (0.459 µmol/l at São Marcos and 0.457 at Olho d'água) were recorded in June (coinciding with the highest concentrations of chlorophyll-a), while the lowest values were observed in September (nitrate: 1.21 µmol/l at São Marcos, 0.820 µmol/l at Calhau and 0.632 µmol/l at Olho d'água and phosphate: 0.368 µmol/l at São Marcos and 0.285 µmol/l at Olho d'água) (Figure 3D, E). The lowest silicate concentrations were recorded in December (49.54 µmol/l at São Marcos and 49.27 µmol/l at Calhau and 53.485 µmol/l at Olho d'água), presumably reflecting the low fluvial discharge during this period (Figure 3F).

The highest concentration of dissolved nutrients (Nittrouer and DeMaster, 1996; Santos *et al*., 2008) in the rainy season could be the principal factor responsible by the local phytoplankton density, which had a much greater biomass (chlorophyll-a concentrations) in March and June, 2009, especially at São Marcos and Calhau beaches when phytoplankton blooms were recorded. Edmond *et al*. (1981) and DeMaster *et al*. (1986) recorded algal blooms on the Amazon shelf during periods of high nutrient concentrations.

CONCLUSION

In conclusion, the obtained results showed that physical processes (climatic and hydrodynamic) were responsible for the control of variation of salinity, turbidity and dissolved nutrients, thus influencing the variation of chlorophyll-a concentrations along the São Marcos bay.

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